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A Multi-Function Guidance, Navigation and Control System for Future Earth and Space Science Missions

Joel Gambino and Neil Dennehy

NASA Goddard Space Flight Center (GSFC)

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Joel Gambino
GN&C Component Engineer
NASA GSFC Code 573
Guidance, Navigation and Control Center
Component and Hardware Systems Branch
Greenbelt, Maryland 20771
joel.gambino@gsfc.nasa.gov

and

Neil Dennehy
Assistant Chief for Technology
NASA GSFC Code 570
Guidance, Navigation and Control Center
Greenbelt, Maryland 20771
neil.dennehy@gsfc.nasa.gov

Over the past several years the Guidance, Navigation and Control Center (GNCC) at NASA's Goddard Space Flight Center (GSFC) has actively engaged in the development of advanced GN&C technology to enable future Earth and Space science missions. The Multi-Function GN&C System (MFGS) design presented in this paper represents the successful coalescence of several discrete GNCC hardware and software technology innovations into one single highly integrated, compact, low power and low cost unit that simultaneously provides autonomous real time on-board attitude determination solutions and navigation solutions with accuracies that satisfy many future GSFC mission requirements. The MFGS is intended to operate as a single self-contained multifunction unit combining the functions now typically performed by a number of hardware units on a spacecraft. However, recognizing the need to satisfy a variety of future mission requirements, design provisions have been included to permit the unit to interface with a number of external remotely mounted sensors and actuators such as magnetometers, sun sensors, star cameras, reaction wheels and thrusters. The result is a highly versatile MFGS that can be configured in multiple ways to suit a realm of mission-specific GN&C requirements. It is envisioned that the MFGS will perform a mission enabling role by filling the microsat GN&C technology gap. In addition, GSFC believes that the MFGS could be employed to significantly reduce volume, power and mass requirements on conventional satellites.

INTRODUCTION

Over the past several years the Guidance, Navigation and Control Center (GNCC) at the NASA Goddard Space Flight Center (GSFC) has actively engaged in the development of advanced GN&C technology for future Earth and Space science missions. Consistent with our commitment to support the GSFC science community the GNCC has pioneered the development of multiple GN&C hardware and software mission-enabling innovations such as the Integrated Reaction Wheel Assembly, MEMS monopropellant thrusters, cold gas microthrusters, low cost spaceborne GPS receivers, MicroElectroMechanical Systems (MEMS) inertial sensors, miniature celestial sensors (star and sun sensors), low noise magnetometers, autonomous GPS-based and celestial-based navigation algorithms, attitude determination algorithms, and unified orbit/attitude control algorithms.

The Multi-Function GN&C System (MFGS) presented in this paper represents the successful coalescence of many of these discrete GNCC hardware and software technology innovations into one single highly integrated, compact, low power and low cost unit that simultaneously provides attitude determination solutions and navigation solutions with accuracies that satisfy many future GSFC mission requirements.

The MFGS is intended to operate as a single self-contained multifunction unit providing autonomous on-board navigation and attitude determination functions. On a given spacecraft it will combine the functions typically performed by a number of hardware units. This MFGS obviates the need for a separate GPS receiver unit, a separate GN&C processor, a separate inertial sensor package and a separate set of attitude control (interface) electronics. This MFGS approach results in reduced mass, power and volume as well as a reduction in the number of unit-to-unit hardware/software interfaces greatly streamlining the level of the GN&C Integration and Test activities.

Recognizing the need to satisfy a variety of future mission requirements, design provisions have been included to permit the unit to interface with a number of external remotely mounted sensors and actuators such as magnetometers, sun sensors, star cameras, reaction wheels and thrusters. The result is a highly versatile MFGS that can be configured in multiple ways to suit a realm of mission-specific GN&C requirements.

An often overlooked challenge associated with implementing future microsats is the lack of available low volume, low cost, low mass, low power GN&C flight hardware for performing the necessary satellite GN&C sensing and actuation functions. It is envisioned that the MFGS will perform a mission enabling role by filling the microsat GN&C technology gap. In addition, GSFC believes that the MFGS could be employed to significantly reduce volume, power and mass requirements on conventional satellites.

OVERVIEW

The MFGS integrated approach provides a versatile solution for a wide variety of spacecraft. The heart of the system is the existing PiVoT GPS receiver. The PiVoT is a GSFC in house design, open architecture receiver designed for space use. The MFGS system adds sensor and actuator capabilities to this existing design to implement a multi-function Navigation/Attitude system in a compact package. Since it is based on the Compact Peripheral Component Interconnect (CPCI) standard, the MFGS is quite flexible. The system can interface with a variety of GN&C hardware and, therefore, can be configured for various missions with different attitude and navigation requirements. The MFGS can accommodate various sensors such as gyros, accelerometers, magnetometers, sun, earth, and star sensors. In addition, the system can drive a variety of actuators including gas thrusters, magnetic torquers, reaction wheels and momentum wheels. By reducing the size of sensors, actuators, and optimizing the electronics, significant reductions in mass and power will be realized. The result is a GN&C system that enables many future missions. GSFC believes that the low mass and power goals of the MFGS make it especially well suited for future Microsat applications.
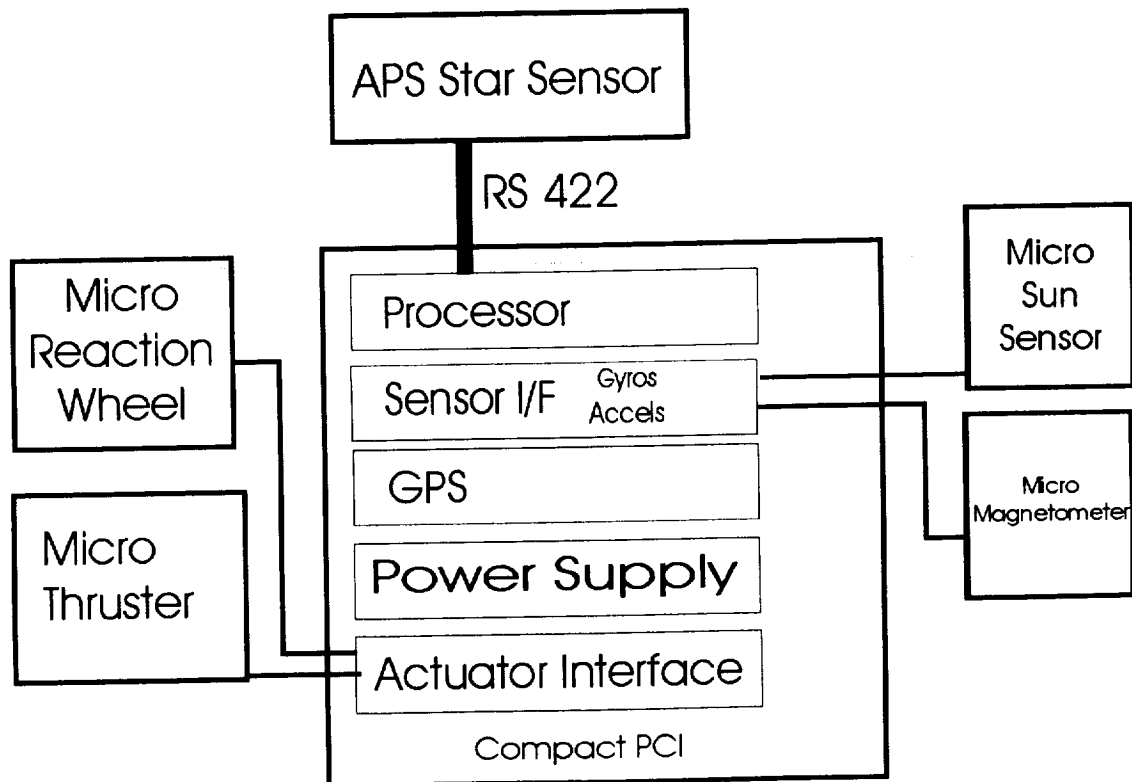

Figure 1: MFGS Block Diagram

Figure 1 shows a block diagram of the MFGS system while Figure 2 is a photograph of the MFGS prototype unit. The GPS receiver and power supply cards are part of the existing PiVoT system. The processor, sensor interface and actuator interface are added as three additional CPCI cards. The processor's RS-422 interface can support star sensors and reaction wheels.
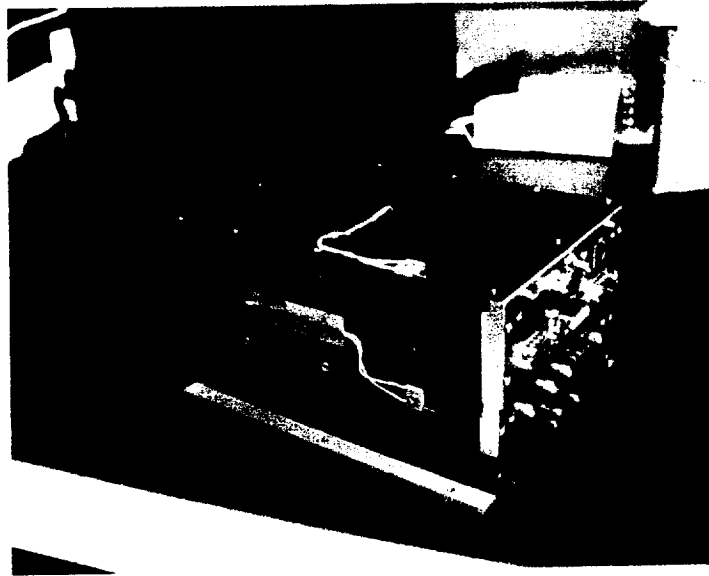

Figure 2: MFGS Prototype Unit

HARDWARE ELEMENTS

PiVoT GPS Receiver

PiVoT (for Position, Velocity and Time) is a space flight GPS receiver designed and built by GSFC. Based on the open-source GPS development system marketed by Mitel (formerly GEC Plessey) Semiconductors, the PiVoT receiver was originally developed to provide a low-cost GPS navigation instrument for NASA's Small Explorer (SMEX) and Spartan series of spacecraft, as well as other GSFC navigation applications. GSFC has continued to pursue the development of this spaceborne GPS receiver technology because of the lack of availability of low cost, low power open-source receivers on which to develop algorithms that could then be tested and then used in the space environment.

PiVoT is an open architecture receiver in both the hardware and software and consists of two 3U size CPCI cards. The current PiVoT card is shown in Figure 3. The PiVoT GPS front-end card is based on the Mitel/GEC Plessey Builder-2 development platform. This card uses two Plessey 2021 correlators to allow tracking of up to 24 separate GPS satellites on unique channels. Its four RF inputs can support four

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independent antennas, making it a useful card for hosting GPS attitude determination algorithms. The design differs from the original Mitel Builder-2 board only in part selection, layout and routing. Higher-grade parts of similar or same values were chosen for environmental concerns and size constraints. By employing a two-sided layout with 12 layers, the total area of each RF input was reduced, all critical nets shortened, and improved shielding provided. This effort resulted in a 1.2 square inch circuit for each RF Front End, with much better immunity to electrical noise from other cards in the CPCI enclosure. Also, the front-end card will track a weaker signal than the original Builder 2 board. It also hosts an improved clock oscillator.

The second card is a space qualified commercial-off-the-shelf processor to compute the navigation and attitude solutions. This card controls the correlators (Plessey's GP2021's) on the front-end card to perform the tracking, despreading (correlating), and demodulation of the GPS signals. Cards that have been used in the past include an industrial grade Pentium 400 MHz CPU with and extended temperature rating and the ESP603 Enhanced Space Processor PowerPC card by EMS Technologies.
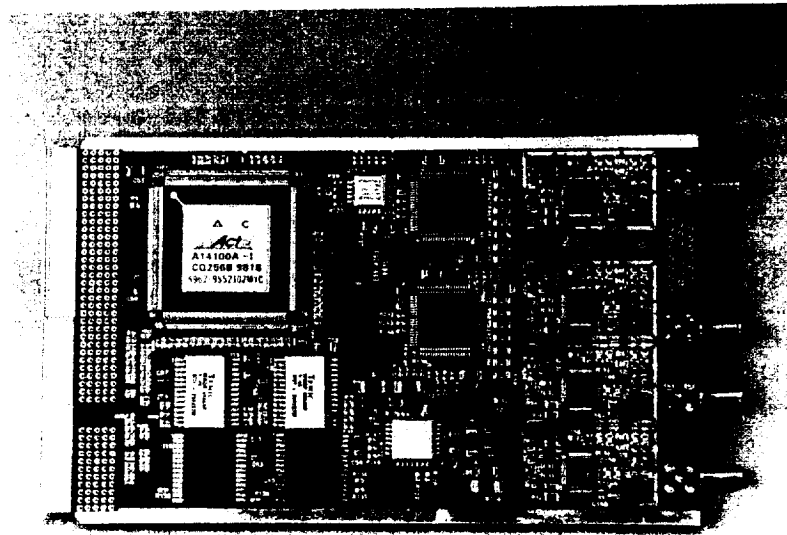

Figure 3: Current PiVoT GPS Receiver Card

A new version of the PiVoT system (presently referred to as PiVoT 1.5) is currently under development that will be half the size (a single CPCI card will contain the GPS front-end and the necessary processor) and require only one third the amount of power. This card will be used in the MFGS.

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Electronic parts used for the next version of PiVoT will meet low earth orbit space grade specifications. Radiation screened parts will be chosen when available. However, some parts will be used based on a similar part's radiation performance history. For example, the GPS chipset, designed by Mitel/Plessey was manufactured with a process similar to some previously screened parts. Preliminary radiation screening was performed on the Mitel/Plessey GPS chipset with positive results up to 25Krads.

The card will contain a 10.0 MHz oscillator to provide the reference for the phase lock loop, local oscillators in each RF front end and the clock for the correlator functions. This reference oscillator was carefully chosen to have a low (1 part per billion) root Allen variance to support navigation software performance. The oscillator is radiation tolerant, and provides better than 1-ppm frequency accuracy over the full temperature range.

The existing version of the PiVoT receiver has been tested on the GSS STR4760 simulator located at GSFC's Formation Flying Test Bed (FFTB). In this FFTB lab environment the open-architecture PiVoT is often used to support the development of new GPS navigation and attitude determination algorithms. The PiVoT test program has also included simulated use on satellites in highly elliptical orbit mission scenarios. The existing PiVoT's first flight opportunity was in July 2001 on the In-FOCUS balloon flown from the National Scientific Balloon Facility, in Palestine, TX. During this balloon flight sufficient data was collected to verify operation of the PiVoT receiver.

The goals for the new PiVoT 1.5 card under development are: low power (7 - 8 watts), radiation tolerant (25 Krads), 24 channels of GPS data, 4 coherent antenna inputs, 3U CPCI interface, and on-card processing. The biggest power drain of the existing PiVoT system is the CPCI interface and the separate processing card. Power will be dramatically reduced on PiVoT 1.5 by using the Hitachi SH-4 7751 microprocessor chip that has an on-chip CPCI bridge, and on-chip memory glue-logic. This chip draws a total of 0.6 watts. The microprocessor will take care of all tracking loop closures and navigation solutions. The output from the card will be position, velocity, and time, via either RS-232 or across the CPCI backplane.

Beyond the development of the PiVoT Version 1.5 unit, the GSFC GNCC technology development roadmap includes the development of a Next Generation (NexGen) PiVoT GPS Receiver for use in High Earth orbits (HEO) and geostationary orbits (GEO). Earth Science and Space Science researchers are envisioning distributed spacecraft and formation flying missions in HEO, and high altitude GPS utilization is an enabling technology to provide the required onboard orbit information to coordinate the multiple spacecraft. Acquiring and tracking GPS signals in orbits above the GPS constellation, however, is much more challenging than using GPS in Low Earth Orbit (LEO). There are important differences in geometrical coverage, signal power levels, and vehicle dynamics. For example, there are rarely four or more satellites visible simultaneously at HEO and there are significant periods in which no signals are available.

Since a receiver that can acquire and track weak signals is critical for use in high altitude orbits, an improved understanding of the nature of GPS signals in HEO and GEO orbits is required to design the NexGen PiVoT receiver. GSFC is currently participating in flight experiments to characterize the GPS signals received by the AMSAT-OSCAR 40 (AO-40) spacecraft which is operating in 1000 km by 58,800 km orbit[1]. The lessons learned from the AO-40 GPS flight experiment will be used to guide the future HEO GPS technology development at GSFC.

The NexGen PiVoT GPS receiver will be designed to survive the extremely severe radiation environment encountered in non-LEO orbits. The NexGen PiVoT will be a software based GPS receiver, and will not use any industry provided GPS chipsets to do signal processing. Doing as much of the signal processing in software as possible will provide the most flexibility and will permit the investigation of new design concepts that drastically deviate from a conventional hardware based approach.

Currently, GNCC has a non-real-time software GPS receiver working in MATLAB (registered trademark of the Math Works, Incorporated) that does signal acquisition, tracking, and demodulation. GNCC partnered with the U.S. Air Force Research Laboratory's Sensor Directorate at Wright-Patterson Air Force Base in developing this software. It acquires and tracks GPS signals with a carrier to noise ratio (C/N_0) as low as 25 dB-Hz. The acquisition algorithm is based on a paper by Dr. Mark Psiaki of Cornell University, "Block Acquisition of Weak GPS Signals in a Software Receiver". The algorithm averages signals over multiple GPS code periods and multiple navigation data bits to achieve weak signal acquisition. It uses the Fast Fourier Transform (FFT) and inverse FFT to process one code period (1 ms) at a time to speed up computations. The software has been tested with simulated and digitized GPS signals[2]. The next step is to port the software to a commercial-off-the-shelf Digital Signal Processor (DSP) in order to test the algorithms in a real-time environment. It is envisioned that as the NexGen PiVoT technology matures, it will be integrated into the MFGS design.

Navigation/Attitude Processor Card

A second processor will be added to the existing PiVoT design to perform navigation and attitude determination/control processing. The PiVoT GPS receiver computational burden is significant and analysis indicates that it is not feasible to share the GPS processor with other functions. The navigation/attitude processor will handle data from the various sensors. Depending on the mission application, appropriate software modules will be loaded to determine position and/or attitude based on data from the available sensors. The processor will be capable of performing all required navigation, attitude determination and attitude control computational functions.

A market survey of candidate processors is ongoing. For this application, a low power, radiation tolerant unit is desired. The Hitachi SH4 7751 is being considered. With its on board CPCI interface and 1 Watt power consumption, it is an attractive unit

although radiation tolerance may be an issue. The Motorola Coldfire processor is also being considered. While it is radiation tolerant, it possesses an external CPCI interface, which would add to the part count on the processor board. A radiation test is planned to assess the radiation tolerance of the candidate processors.

Sensor Interface Card

Figure 4 shows the block diagram for the sensor interface card. Signals from the MEMS gyros accelerometers, and magnetometers are conditioned and provided to the CPCI bus through the FPGA. The MEMS gyros provide analog voltages (approximately 0-1 V) for temperature and rate. The accelerometers provide a 0-5V signal and the magnetometers provide a +/- 4V output. The gyros and accelerometers are powered from a +5V supply while the magnetometer requires a +/- 5V supply. The signals from the rate sensors, accelerometers, and magnetometers are amplified to provide maximum sensitivity to the A/D converter. Once the proper range is obtained, the signals are fed through a multiplexer to the A/D converter. The multiplexer addressing is handled by the glue logic. The digitized sensor data is then fed to Random Access Memory (RAM) by the glue logic where it is made available to the processor via the CPCI interface.
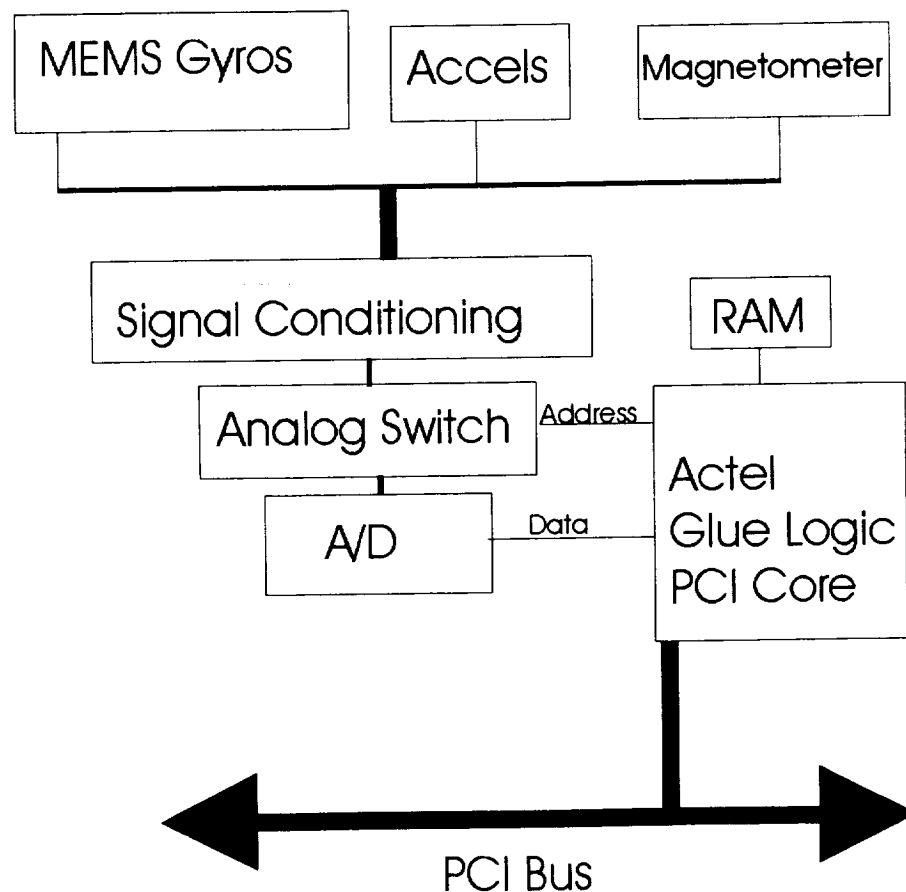

Figure 4: Sensor Interface Board

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The interface to the CPCI bus will be via an Actel FPGA containing both the glue logic and Actel's Core PCI. The Actel Core PCI provides a low-power flexible platform that provides CPCI routing resources and memory controllers. Using the Actel 54 SX device family, glue logic and the CPCI interface can reside in a single FPGA.

The glue logic addresses the multiplexer and reads the data from the A/D converter. The data is then written to memory to await a request from the processor. When a request is received, the data is passed through the glue logic to the processor via the CPCI bus.

MEMS Rate Sensors

There is a widespread interest within the spacecraft development community to incorporate MEMS technology in the design of future space systems. MEMS-based devices have the advantages of small volume, low mass, low power and high resistance to the space environment[3]. In particular, MEMS sensors and actuators hold the promise of revolutionizing satellite GN&C design[4]. Based upon the results of recent feasibility trade studies, GSFC decided to incorporate MEMS rate sensors into the MFGS design.

The MEMS rate sensors currently being used in the prototype MFGS are the Boeing Beta Rate Sensors[5]. Three units will be used to provide rate information about three axes. The sensors, which have a four wire interface, are supplied with +5 V and ground, and provide angular rate and temperature outputs. Temperature data is provided for drift compensation. Each rate sensor, which has a mass of 35 grams and consumes only 60 mA of current, has a rate range is +/- 25 deg/sec.

The MEMS rate sensors utilize advanced silicon micromachined gyro technology to measure inertial rates. As depicted in Figure 5, sense elements etched in silicon are driven to oscillate back and forth by electrostatic drive motors. When an inertial rate is applied about the input axis, the vibrating masses are displaced in a direction normal to both the driven oscillation and the input axis. Capacitive sense plates measure the displacement of the vibrating masses, which is proportional to the applied rate.

These particular Boeing Beta MEMS rate sensors were selected because they were already available in test at the GSFC Actuator/Sensor Laboratory. While they do not represent the latest advancements in MEMS rate sensor technology development, the performance of these Boeing Beta Rate Sensors is adequate for a prototype MFGS demonstration unit. Higher performance units are obviously desirable and plans are being made to integrate advanced MEMS inertial sensor technology later in the MFGS development program. Several vendors are developing high performance MEMS rate sensors including JPL, Honeywell, Kearfott, Draper Laboratory and L3, among others.
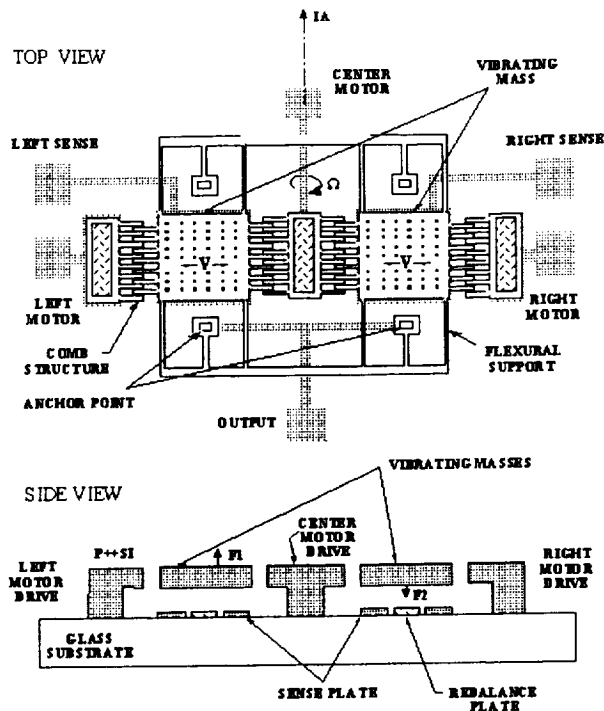
Figure 5: MEMS Rate Sensor

MEMS Accelerometers

The MEMS accelerometer package currently being used is the Analog Devices ADXL05 EM-3. It is a tri-axial unit that operates on a single +5V supply and consumes approximately 0.12 W. The dynamic range is +/- 4g represented by the output voltage of +/- 2 V.

Actuator Interface Card

An actuator interface will be developed to drive attitude control actuators such as magnetic torquer bars, gas thrusters, and reaction wheels. Constant current sources are provided on the card to drive magnetic torquers while solid state switches for thruster valve on/off control. The current design provides for an RS-422 interface from the processor to the reaction wheels so therefore no wheel drive electronics are currently designed into the actuator interface.

SOFTWARE ELEMENTS

PiVoT GPS Software

The current PiVoT software is based on the original open-source Plessey Builder 2 software ported to the Linux operating system. The software is POSIX complaint and can easily be converted to other POSIX operating systems. Improvements were made to the original Plessey software to make it suitable for an orbital environment, to include removing height limits and changing Doppler bin widths and dwell times. Additional

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tasks can be added to the software to support GPS science experiments or attitude determination algorithms.

The Linux solution, however, while ideal for the lab, cannot guarantee real-time performance. Thus, the new single card PiVoT (Version 1.5) will host the processing software using the Nucleus real-time operating system. This will decrease code size, and increase real-time performance due to lower operating system overhead.

GEONS Navigation Software

The MFGS design includes the GPS-Enhanced Onboard Navigation System (GEONS) software. This GSFC-developed software improves the accuracy of GPS-generated three-dimensional position and velocity fixes. GEONS produces a robust orbit determination capability, not just positioning with GPS. It can provide reliable position and velocity estimates with fewer than four GPS satellites in view and has been designed for seamless performance through GPS satellite handoffs.

EXTERNAL SENSORS/ACTUATORS

As mentioned above, the design of the MFGS includes the provision for interfacing with external attitude sensors and actuators. In particular, it is planned to provide the near term capability to interface the MFGS with an Active Pixel Sensor (APS) star sensor, a Micro-Magnetometer, a Micro/Nano reaction wheel as well as, in the long term, with MEMS thrusters. These advanced technology sensors and actuators are described below.

APS Star Sensor

GSFC is currently developing a star sensor that utilizes APS technology to replace the traditional Charge Coupled Device (CCD) technology present on commercial star trackers available today. Future microsat missions will benefit from the APS technology through smaller, lighter, lower-power imaging units, coupled with an increase in sensor accuracy and usable field of view. Also, the APS is proving to be more radiation tolerant than the CCD and should provide better end-of life performance for the unit as a whole.

The APS detector architecture and operation is vastly different than the more commonly used CCD imaging devices. Although widely used in personal computer imaging and conferencing, the APS camera applications have yet to be applied strategically to the aerospace field. Under two recent NASA Small Business Innovative Research (SBIR) awards, Photobit Corporation of Pasadena, CA, developed a specialized APS detector uniquely designed for stellar sensing applications. Leveraging from this emerging technology GSFC was awarded a NASA Research Announcement (NRA) through the Explorers Program Office to develop, build, and ultimately license an APS star sensor to the commercial sector for spacecraft applications. This program is

currently in the second year of development, and is at a Technology Readiness Level of approximately four (TRL 4).

System performance measurements are still being tested and evaluated. It is estimated, however, that the APS star sensor will have an accuracy of 5-10 arc seconds, weigh about 2 kg, and consume less than 5 W total power.

Micro-Magnetometer

A Crossbow CXM113 3-axis fluxgate magnetometer system is used to measure magnetic field. This unit is packaged on a PC board as a development package. It is operated by an input voltage of +/- 5V. The dynamic range is +/- 1 Gauss represented by the output voltage of +/- 4 V. The unit consumes approximately 0.18 watts.

Micro/Nano Reaction Wheel

GSFC has designed a new class of Reaction/Momentum Wheels that will support the requirements of future missions including constellations of Micro- and Nano-satellites. There are no reaction wheels currently available which meet the requirements of such missions for low power and miniaturization. The proposed development will use recent advances in miniaturization of electronics to solve this deficiency.

The proposed Micro/Nano reaction wheel performance will be at least ±0.0018 N-m-sec of momentum storage with at least ±50 μN-m of torque and less than 0.1 W steady state power at maximum speed, with the goal of fitting within a 2.5 cm cube. The Micro-wheel performance will be at least ±0.024 N-m-sec of momentum storage with at least ±550 μN-m of torque and less than 0.4 W steady state power at maximum speed, with the goal of fitting within a 5 cm cube.

The control electronics developed for this wheel will be designed to support a variety of motors, allowing for multiple torque/momentum configurations. The control electronics will also incorporate a variety of command modes to support either speed or torque control of the wheel with the simplest practical external interfaces. The control electronics will be housed within the wheel envelopes mentioned above.

MEMS Monopropellant Micro-Newton Thruster

Over the past several years, MEMS monopropellant thruster development has been conducted by the GNCC's Propulsion Branch[6]. This work has been supported by the MEMS technologists within the GSFC Instrument Technology Center (ITC) with prototype MEMS thruster hardware being fabricated on-site at GSFC using the ITC's Detector Development Laboratory (DDL) facilities and equipment.

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The overall goal of the program is to develop scalable micro-Newton level monopropellant thrusters that would enable formation flying and nano-satellite missions. The early effort has been focused on determining the feasibility of constructing MEMS catalytic thrusters and determining scaling relationships. The current effort is focused on applying the information obtained from the feasibility and scaling studies to produce a second generation of catalyst chambers targeting specific thrust levels and efficiencies. In addition to implementing improvements in the thrust chamber design and experimentally verifying performance parameters of the second generation of thrust chambers, the current effort addresses MEMS thruster system-level issues such as the total throughput capability of the reaction chambers and evaluation of MEMS valve concepts. The reacting micro-fluid flow is being modeled using computation fluid dynamics methods. Performance analyses are being performed to study the tradeoffs between chamber paths, catalyst channel aspect ratios, nozzle lengths, and catalyst materials. Direct performance testing of the MEMS thrusters will be conducted at GSFC on a micro-Newton level thruststand.

The on-going MEMS monopropellant effort utilizes hydrogen peroxide as a propellant. The targeted thrust level range is between 10 and 500 μN with impulse bits between 1-1000 uN· sec and an I_{sp} of greater than 110 sec. Individual reaction chambers are approximately 3 x 2.5 x 2 mm. Thrust chambers are etched in a 0.5 mm silicon substrate and vapor deposited with silver using a catalyst mask. The chamber fabrication process is completed by anodically bonding glass to the substrate, diamond cutting each chamber from the wafer, and then integrating propellant feed tubes.

MEMS catalytic monopropellant propulsion systems have the potential to enable future missions that require micro-propulsive maneuvers for formation flying and precision pointing. Current propulsion technology cannot meet the minimum thrust/impulse-bit requirements (10-1000 μN/1-1000 μN· sec) or the extremely limited system mass (<0.1 kg), volume (<1 cm3), and power constraints (<1W). When compared to other proposed micro-propulsion concepts, MEMS catalytic monopropellant thrusters show the promise of the combined advantages of high specific density, low system power and volume, large range of thrust levels, repeatable thrust vectors, and simplicity of integration.

PREDICTED PERFORMANCE

The MFGS performance capabilities will largely depend on the individual mission requirements and the available set of navigation/attitude sensor data. The MFGS will utilize a single navigation software system architecture for which the performance capabilities can be tailored for individual missions. The primary navigation software element used in the MFGS is the GEONS (Ref. 7, Section 4.2, Autonomous Navigation Technologies) which is a multipurpose navigation software package developed by NASA/GSFC that can easily be reconfigured to mission-unique needs.

GEONS is based upon the GEODE software, a runner-up in NASA's 2000 Software of the Year competition, which has successfully been transferred to industry, academia and other U.S. government agencies. GEONS significantly improves the accuracy of GPS generated position and velocity fixes. In simulations using NASA LEO satellite data, GEONS filtered GPS data produced position accuracies to better than 20 meters and velocity accuracies to better than 0.03 meters per second. Future versions of the GEONS navigational software have target performance goals of 10 meters and 0.01 meters per second for 3-D position and 3-D velocity accuracies, respectively, for LEO satellite mission applications[8]. GSFC's simulation results indicate navigation performance of 100 meters for position determination and 0.1 meter/second velocity determination for satellites operating in flight regimes well above the GPS constellation.

The MFGS can also provide a magnetometer based navigation capability[9]. Simulation, analysis and modeling has shown that magnetometer based navigation is a low cost, low complexity approach that can provide reliable solutions in a LEO flight regime. Analytical testing of the magnetometer/gyro sensor combination showed example performance results of 15-25 km in orbit determination accuracy with attitude determination of 0.2-1.4 degrees. A magnetometer/GPS sensor combination yields meter-level orbit determination accuracy along with an attitude determination capability of less than 0.3 degrees. It is expected that the magnetometer based navigation could either be employed in a backup mode of operation, a initialization mode for another system, or as a the prime navigation system for those LEO missions with moderate accuracy requirements. Flight experiments are planned on-board GSFC's WIRE SMEX-class spacecraft for later this year to validate the predicted navigation performance levels of this configuration.

Attitude performance of the MFGS is currently being analyzed and simulated. Attitude determination performance goals for the MFGS range between 0.1-0.3 degree without the external APS star sensor data and 1-2 arc-seconds with the external APS star sensor data.

SUMMARY

This paper has highlighted the top-level design of a Multi-Function GN&C System (MFGS) currently being developed at NASA GSFC. This MFGD represents the successful coalescence of several of GSFC's GN&C hardware and software technology innovations into one single highly integrated, compact, low power and low cost unit that simultaneously provides attitude determination solutions and navigation solutions with accuracies that satisfy many future GSFC mission requirements.

While the MFGS is intended to operate as a single, self-contained, multifunction unit, design provisions have been included to permit the unit to interface with a number

of external, remotely mounted, sensors and actuators such as magnetometers, sun sensors, earth sensors, star cameras, reaction wheels and thrusters.

The result is a highly versatile MFGS that can be configured in multiple ways to suit a realm of specific mission GN&C requirements. It is envisioned that the MFGS will perform a mission enabling role by filling the microsat GN&C technology gap. In addition, GSFC believes that the MFGS could be employed to significantly reduce volume, power and mass requirements on conventional satellites.

ACKNOWLEDGEMENTS

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